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Piezoelectric micro-pump with PZT thin film for low consumption microfluidic devices

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Abstract

We report on the first peristaltic micropump with active microvalves actuated by piezoelectric thin-films. We developed an original process to combine state of the art sol-gel $Pb(Zr,Ti)O_3$ (PZT) thin-films with a highly performing silicon micropump. The device thus takes advantage of both technologies, especially with respect to low voltage actuation and high precision. It can produce µl/min flows for 24 V actuation voltage, opening a new range of applications for low consuming pumps and autonomous microfluidic systems, especially implanted devices for drug delivery.

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Keywords: micro-pump; PZT thin films; microfluidic devices

1. Introduction

As key components of microfluidic devices, micropumps have been intensively studied so far. Among many different technologies, piezoelectric bulk ceramic micropumps exhibit many advantages for microfluidic applications [1]. However, they require high voltage, which is a major drawback for autonomous and implanted systems. Moreover, the packaging of ceramics is expensive. The development of PZT thin-films with high mechanical response for low voltage offers a suitable solution for both issues [2]. Few micropumps with piezoelectric thin films have been reported so far [3,4]. They show low performances mainly because they use non

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actuated valves, like diffusers or check-valves, and not optimized piezoelectric material, strongly limiting the range of applications. In this paper, we propose to combine the existing design of a micropump previously developed at CEA LETI [1] with optimized PZT thin films [2]. The general purpose of this study is to assess the propensity of PZT thin films to actuate micropumps at low voltage, and more specifically below 24 V, which is highly desired for medical applications.

2. Technology

The micropump is made of three aligned 50 µm-thick silicon membranes as described in Fig. 1. The whole device is 3 cm-wide, with 7.5 mm-outer-diameter membranes.

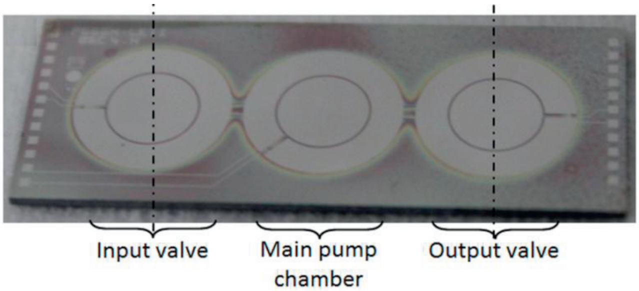

Fig. 1. Top view of the final device revealing the peristaltic design.

This design is based on the peristaltic principle as described by Jang [5]. Both valves are active, which means that they are controlled by the piezoelectric layer through the application of an external electric field. Fig. 1 shows the top electrode pattern based on two circular shapes, being respectively inner and outer actuators. They give the opportunity to move both valves and main pump membranes up and down. Using finite element simulation, their dimensions are calculated in order to optimize the total displaced volume. This special design is necessary as PZT films are utilized at a very strong electric field, which prevents using PZT as a proper piezoelectric material. In this configuration, PZT is mainly electrostrictive and therefore exhibits the same strain at strong positive or negative voltage for a given voltage magnitude. The inner actuator moves the membrane down while the external one moves it up. Note that PZT films always shrink in plane when a strong voltage is applied.

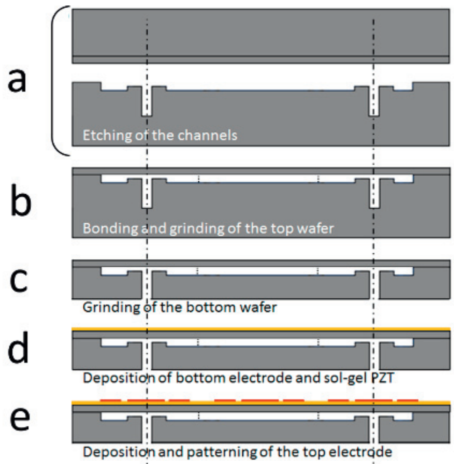

Fig. 2. Technological flowchart.

Fig. 2 shows the technological flowchart based on 200 mm silicon wafers. The process is based on a two-wafer bonding step. First, the channels are etched into the bottom wafer (cf Fig.2a). Three Deep Reactive Ion Etching (DRIE) steps are required to process the different thicknesses required to realize the valves and to prepare the final release.

The top and bottom wafers are then assembled by SiO_2/SiO_2 molecular sealing (cf Fig. 2b) and annealed at 1100 °C. The main constraint here is to keep the 1 µm-gap between the two wafers at the location of each valve on the whole sealed area, corresponding to 200 mm wafers. The top wafer is then thinned by grinding. As it is an SOI wafer, the final approach is performed by TMAH wet etching, stopping when the Burried Oxyde (BOX) is reached. The final silicon membrane thickness is 50 µm. The 2 µm-thick BOX is kept for the subsequent steps. The bottom wafer is then grinded as well in order to open the structure and reveal the channels (cf Fig. 2c). The two last steps are dedicated to the realization of the PZT films. On the BOX is deposited 20 nm-thick TiO_2 plus 100 nm-thick Pt, acting as bottom electrode. Then, 1.5 µm-thick sol-gel PZT layer is deposited by processing 28 successive layers, as depicted in [2]. The maximum processing temperature is 700 °C, required in order to crystallize PZT in the desired perovskite crystallographic structure. The final step is the deposition and pattern of the top electrode, made of 100 nm-thick Ru. Dry etching and stripping techniques were then used in order to preserve clean fluidic channels.

The finalized device is then mounted in a fluidic circuit enabling to assess flow rate versus applied voltage and back pressure influence.

3. Results and discussion

Fig. 3 shows the influence of an external applied backpressure on the position of the membrane of the input valve together with the leakage flow rate. Note that 24 V is permanently applied to the inner actuator of the valve for this experiment. This last proves that the leakage flow rate remains null until the back pressure reaches 40 mbar. This leakage is indeed correlated with the valve position that stays at -1 µm as long as the back pressure is smaller than 40 mbar. It shows that the valve is actually the weak link to withstand the backpressure, though this value is already of interest for applications.

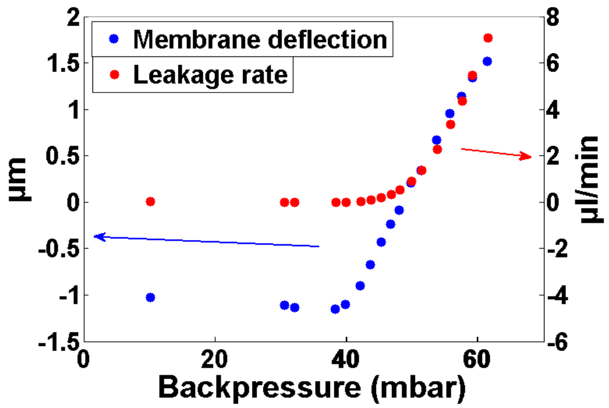

Fig. 3. Valve membrane deflection and leakage flow rate through the valve versus the applied back pressure. 24 V-bias voltage is constantly applied to the valve inner actuator in order to keep it closed.

Finally, Fig. 4 shows the water flow rate of the pump actuated at 24 V for all actuators (valves and central membranes) at different frequencies from 0.2 to 5 Hz. The flow rate increases linearly until 1 Hz, reaching its maximum value, namely 3.6 µl/min. The flow rate tends to saturate beyond 1 Hz, which is related to water viscosity. It is remarkable to notice that the actuation voltage is limited to 24 V, which does not prevent the pump from working properly. It also worth mentioning that the pump can work reversibly, meaning that the liquid can be pumped in and out. The overall consumption of the pump is 0.3 mW when actuated at 24 V and 1 Hz.

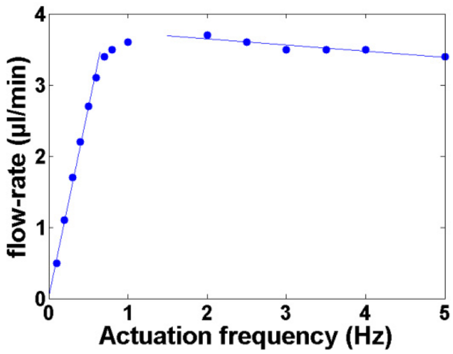

Fig. 4. Flow rate versus the actuation frequency in peristaltic mode. The applied voltage is 24 V for all points displayed. The solid line is a guide for the eyes

4. Conclusion

In this paper, we realized a micropump working on the peristaltic mode based on PZT thin films and active valves. The overall results are an actuation voltage as low as 24 V, a back pressure of 40 mbar, a flow rate reaching 3.6 µl/min and a consumption limited to 0.3 mW.

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